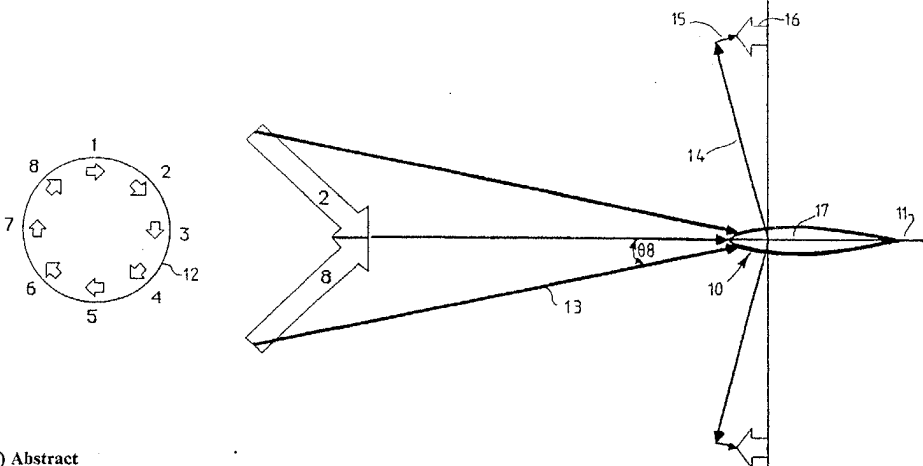


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<b>(54) Title:</b> WAVE ENERGY DEVICES <div style="display: flex; align-items: center; justify-content: center;">  </div> <b>(57) Abstract</b> <p>Wave energy devices which employ the properties of aerofoil sectioned wings to extract energy in the form of thrust from water agitated by waves, wherein the wing (10) is positioned as close as practicable to the surface, where water movement is at its maximum, and constrained against substantial movement perpendicular to the transverse chordal plane (17) of the wing thus utilizing the kinetic energy of the moving water directly to produce a nett thrust (16) in the chordal plane of the wing. In one form, aerofoil sectioned wings may be fitted to the hull of a ship to project laterally therefrom and be subject to wave motion. In alternative forms, aerofoil sectioned wings may be applied to rotors submerged in wave agitated water, thrust generated in the wings causing rotation of the rotor to drive a load. Support means to vary the attitude of the wings within a predetermined range of angles of attack relative to apparent flow of the water are also disclosed.</p>		

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WAVE ENERGY DEVICES**Technical Field**

This invention relates to a method and means for extracting energy in the form of thrust from waves and in particular to a method of and means for generating nett thrust in a preferred direction from the kinetic energy of moving water in waves for application to water craft to assist in the forward motion thereof or for driving a load such as electrical power generating means.

**Background Art**

Many different devices for extracting energy from waves have been proposed in the past. Generally, such devices have been suggested in order to enable the generation of electrical power from wave motion and in most cases include a floating body or bodies and complex mechanical or hydraulic power take off means to enable the oscillating movement or relative movement of the floating bodies to be converted into useful power. The known devices are generally massive, with a low output of power per unit of mass, complex and unable to generate power from a broad spectrum of wave periods, as they need to be "tuned" to a particular wave period and are quite inefficient in waves of other periods. The above described arrangements are of course limited to the generation of electrical power and are not applied to or applicable to providing thrust for water craft.

In a further arrangement, a 'foil propeller' which utilises the interaction of a deeply submerged adjusting aerofoil wing (controlled in its attitude by spring or hydraulic resistance) & either wave induced boat motion or engine produced vertical movement in the wing to generate thrust has been proposed. In this proposal, the wing is intended to be moved vertically either by the pitching of the boat, ship or other floating body to which it is attached, the floating body acting as a collector of wave energy in the form of movement perpendicular to the direction of travel. Alternatively, the wing is moved by power supplied by an engine or other power source.

The present invention aims to provide means for extracting energy in the form of thrust directly from the kinetic energy of the water close to the surface, moving due to wave action, for application in a first instance (linear) to water craft to assist or comprise the motive power for such craft and in a further aspect (rotary) to electrical generation or other load, by employing the properties of suitably constrained aerofoil wing sections immersed in and interacting with the surface water agitated by wave action. As opposed to the arrangement referred to above, in the present invention, the wing or wings are positioned as close as practicable to the surface where water movement is at its maximum and constrained against substantial vertical movement thus utilizing the kinetic energy of the moving water directly rather than using the wave induced movements of the floating body to move the wing or wings.

**Disclosure of Invention**

With the above and other objects in view the present invention resides in a first aspect in a method of extracting energy from waves by using an aerofoil sectioned wing and cause said wing to move in a desired direction along a path, comprising the steps of

(1) at least partially submerging said wing in water agitated by wave action with its leading edge forward in the said direction of travel and its chordal plane substantially parallel to said direction.

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(2) supporting said wing for movement along said path and

(3) constraining said wing against substantial movement perpendicular to said path.

The constraint for the wing may comprise an external fixed mounting such as the seabed

or a body having a large external mass, that is a body having a natural period of oscillation substantially slower than the ambient wave period. Alternatively, the constraint for the wing may comprise an external object or arrangement of objects placed deeper below the surface where water movement is less, having a hydrodynamical resistance to perpendicular movement.

In an alternative aspect, many wings or assemblages of wings for example, in the form of rotors may be rigidly interconnected and spaced over a distance preferably longer than the wave length of the waves so that individual wings or assemblages of wings, being at different positions in the wave cycle, generate forces perpendicular to the direction of wing motion that oppose the perpendicular forces generated by other individual wings so that forces perpendicular to the direction of travel cancel each other out.

In yet another alternative aspect, the present invention provides one or more elongated wings, supported at intervals as necessary, preferably as long as or longer than the wavelength of the ambient waves so that different areas along a wing are acted upon by different parts of the wave cycle so that whilst some areas along the length of the wing experience a perpendicular force in one direction, other areas experience a counteracting perpendicular force and thus the nett forces perpendicular to the wings direction of movement are minimal or zero effectively constraining each wing or assemblages of wings by a statistical averaging effect.

In one preferred arrangement the wing or wings are supported for rotation about an axis in a rotor assembly adapted to be associated with power generating means or other load. The swept path of said wing or wings may constitute a planar, conical, spherical, cylindrical or any other surface and the rotor assemblies may be individual or ganged together in any number.

In another preferred arrangement, the wing or wings may be secured to the hull of a ship or other body to extend laterally thereof and at suitably spaced apart positions along the hull to be exposed to water agitated by wave action and so that the leading edges of the wings are forward in the direction of normal movement of the vessel and the chordal plane thereof is substantially parallel to that direction. So that the lift force components in a direction perpendicular to the chordal planes substantially cancel each other out, the region of the body supporting the wings is suitably longer than the wave length of waves encountered. Preferably such wings are pivotally mounted to the hull for movement about a substantially vertical axis to be pivotal from a laterally extending operative position to an inoperative position adjacent to the hull. Suitably biasing means are associated with the wing or wings to permit pivotal movement thereof against the bias in the event of an obstruction being encountered or the wings being overloaded. The wing or wings may, as well as or as an alternative to the above, be provided with a pivotal connection to the hull to permit limited pivotal movement about a substantially horizontal axis against a bias to absorb overloads caused by exceptionally large waves.

In each of the above situations it is preferred that the wings have a high aspect ratio preferably greater than five to one to maximise energy transfer from the waves.

#### Brief Description of Drawings

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Reference will now be made to the accompanying drawings which illustrated preferred embodiments of the invention and wherein :-

Fig. 1 illustrates schematically the principles of wave motion

Fig. 2 illustrates schematically the principles of generating thrust from a aerofoil sectioned wing subject to wave motion.

Figs. 3 and 4 illustrate in plan and elevational views a ship provided with aerofoil sectioned wings according to the present invention

Figs. 5 (a) to (d) illustrate a preferred means of mounting the wings to the hull of the ship of Figs. 3 and 4 and various modes of the wing

Fig. 6 illustrates in sectional view the preferred means of control of the wing attitude

Fig. 7 is an elevational view of a yacht provided with adjustable aerofoil wing assemblies according to the present invention.

Figs. 8 and 9 are respective plan and elevational views of a preferred form of adjustable aerofoil wing assemblies

Figs. 10 and 11 are perspective views of the support core and wings of the wing assembly of Figs. 8 and 9

Figs. 12(a) to (d) illustrate the manner of adjustment of the wing assembly of Figs. 8 to 11

Figs. 13 and 14 illustrate alternative forms of adjustable wing assemblies

Fig. 15 is a perspective partly cut away view of a further alternative form of adjustable wing assembly

Fig. 16(a) to (d) illustrate various attitudes of the wing assembly of Fig. 15

Fig. 17 illustrates the basic form of a simple rotor according to the invention

Figs. 18 and 19 illustrate in plan and elevational view an alternative form of rotor assembly

Fig. 20 is a perspective view of ganged rotor assemblies of the type illustrated in Figs. 18 and 19

Fig. 21 is a perspective view of a cylindrical rotor assembly according to the present invention

Fig. 22 is an end view of the rotor of Fig. 21 in its operative attitude relative to wave motion.

Figs. 23 to 27 illustrate various applications of the above rotor assemblies.

#### Best Mode for Carrying Out the Invention

Referring to the drawings and firstly to Fig. 1 there is illustrated schematically the motion of water particles in a wave. As illustrated by the arrows, the water particles revolve in a generally circular path or orbit at or below the surface of the water and the motion of the particles and the position they occupy give the wave its shape at any particular time. A normal ocean surface represents the sum of motions generated by many simple wave patterns of different lengths, amplitudes and directions. Each of the component wave patterns influence each particle of water and this influence may be expressed as a vector of velocity and direction. It is an object of the present invention to derive from the kinetic energy of the water particles close to the surface of the water a usable thrust using aerofoil sectioned wings.

As illustrated in Fig. 2, an aerofoil sectioned wing 10 in accordance with the present invention is arranged for movement along a path 11 so as to be subject to the motion of various water particles of a wave some of which are represented by the arrows numbered 1 to 8 about the circle 12. If the vector arrow 8 is considered,

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the apparent flow as seen by the moving wing is represented by the vector arrow 13 which is at an apparent angle of attack of  $\theta$  to the wing 10. In accordance with the properties of aerofoil sectioned wings a lift force perpendicular to the apparent flow as represented by the vector arrow 14 will be generated. Whilst drag (represented by the vector arrow 15) is also created parallel to the apparent flow, a resultant thrust represented by the arrow 16 will be generated parallel to the wing chord 17 (provided that the angle of attack of the wing is greater than the lift/drag angle). A similar situation exists when water particle flow represented by the vector arrow 2 is considered.

For water particle flow in the positions indicated by the arrows 2,3,4,6,7 and 8 a nett thrust in the relative direction of movement of the wing 10 is created. At positions 1 and 5 at the crest and trough of the wave a nett drag is created however this only lasts for a small proportion of the cycle so that an overall nett thrust results in the relative forward moving direction of the wing 10.

The generation of thrust as above may be applied to many different situations for example to a ship 18 as illustrated in Figs. 3 and 4. In this embodiment, the ship 18 is provided with a plurality of aerofoil sectioned wings 19 which are fixedly secured to opposite sides of the hull 20 of the ship 18 at spaced intervals to project in use laterally outwardly therefrom. The ship 18 acts as a rigid spine linking the wings together so that the components of the lift forces, generated by the wings under the influence of the wave generated water movement, perpendicular to the direction of travel substantially counteract each other and thus act as a statistical constraint against substantial movement of the wings 19 in a direction generally perpendicular to the forward motion of the ship (and wings) which in this instance is substantially horizontal. Interaction of the wings 19 with the waves occurs also because the ship, having a large mass, has a natural period of oscillation substantially greater than the ambient wave period and also substantial inertial, hydrodynamic and archimedian resistance to acceleration perpendicular to its direction of travel.

In accordance with the principles described above, the wave motion acting upon the respective wings 19 will cause generation of thrust by each wing 19 in the direction of forward motion of the ship 18 to thereby assist in that forward motion enabling a reduction in drive power required to be produced by conventional drive systems and thereby a reduction in fuel costs. Any motion which the ship 18 develops due to the waves such as roll or pitch will also be converted by interaction of the wings 19 with the water to a nett forward thrust and further stabilise the ship 18 as such motions will be damped by being converted to thrust. Preferably the wings 19 have a high aspect ratio for maximum efficiency of energy transfer and preferably greater than five to one.

The wings 19 as above may be secured to the ship during construction or alternatively be retrofitted to existing ships. For this latter purpose, and as illustrated in Figs. 5 (a) to (d), a hollow elongated spine 21 carrying the wings 19 may be secured to opposite sides of the ship's hull 20 for example by welding.

Preferably, the wings 19 are secured to the spine 21 for pivotal movement about a generally vertical axis 22 and the spine 21 is provided with a longitudinal slot or recess 23 so that the wings 19 may be pivoted from an outwardly extending attitude shown in Fig. 5(b) to a folded stowed attitude shown in Fig. 5(a) where the wings 19 are located substantially wholly within the recess or slot 23. This arrangement permits the wings to be stowed against the side of the ship for docking or other purposes. Preferably also and as shown

in Figs. 5(c) and (d), the wings 19 are constructed so as to be pivotal in a vertical plane under the influence of a biasing force so as to relieve overstressing of the wings. The above principle of energy extraction from waves to apply a thrust force to vessels may be applied to torpedoes, submarines or surveillance vessels where it is important that the motive power be as quiet as possible.

5 Fig. 6 illustrates a preferred mechanism for controlling the wing 19 in the above manner. In this arrangement the wing 19 includes a first part 24 provided with a pivot pin 25 which is mounted for rotation about a vertical axis in bearings 26 in the spine 21 and a second part 27 pivotally connected to the first part 24 for pivotal movement about a horizontal axis suitably by means of a further pivot pin 28. An hydraulic or pneumatic ram 29 is located in the spine 21 and includes a plunger 30 which may act upon a flat 30 formed in  
10 the shaft 25 to maintain when the ram is pressurised, the wing 19 in an outwardly extending operative attitude. The pressure applied to the plunger will determine the release point of the wing 19 to permit the wing to pivot forwardly or rearwardly in the event of momentarily overstressing by waves larger than the design limit or by floating objects, whilst when the wing 19 is to be moved to its inoperative attitude shown in Fig. 5(a), hydraulic pressure is released to remove the bias.

15 The second part 27 of the wing 19 is preferably maintained in a substantially horizontal attitude or in an attitude where its chordal plane is substantially parallel to the direction of motion by further biasing means 31 arranged within the first part 24 of the wing. In this instance the biasing means 31 comprises a spring loaded plunger 32 arranged for reciprocation in a recess 33 within the wing part 24. The plunger 32 is normally biased into engagement with a flat 34 on the end of the wing part 27 to maintain that part in an  
20 outwardly extending attitude however in the event of overstressing, the wing part 27 may overcome the biasing force of the plunger 32 and pivot in a vertical plane. Of course, the wing part 24 need not have an aerofoil configuration and it will be realised that many different biasing structures may be employed to achieve the above results. The biasing arrangements may also be employed separately or in combination.

In a further embodiment, aerofoil sectioned wings may be applied to the hulls of small boats or yachts as  
25 shown in Fig. 7. In this instance, the yacht 35 includes wing assemblies 36 supported on or in the hull 37 adjacent to the bow, keel and skeg. Smaller boats and yachts are generally shorter than the wavelengths of waves they encounter, travel at slower speeds than large ships, and are generally subject to greater pitching and rolling motion than encountered by ships. In such situations the angle of attack of the flow of water impinging upon fixed wings may increase to such an extent so as to cause the wing to stall. To overcome  
30 this disadvantage, the wing assemblies 36 illustrated in Fig. 7 are made self-adjusting so that the angle of attack of the symmetrical aerofoil wing sections 38 of the wing assemblies 37 do not exceed the optimum angle. For this purpose and as more clearly illustrated in Figs. 8 to 11, each wing assembly 36 includes a support core 39 which may be suitably formed from extruded nylon or other material and which is mounted through the hull, keel and skeg of the yacht in any suitable manner for example by forming a hole  
35 therethrough to neatly accept the core 39 which is cut to an appropriate length to fit neatly in position and which may be secured in position by adhesives, fibreglass or the like. The pair of opposed wing sections 36 are provided on their operative inner ends with respective brackets 40 which are fixedly interconnected by a pair of upper and lower pivot bars or shafts 41 offset on opposite sides from the central chordal plane of the

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wings 38 and rearward of the centre of lift effort of the aerofoil section as shown more clearly in Figs.12(a) to (d). The angle between the line extending between the pivot axes of the pivot bars and the centre of effort and a line perpendicular to the chordal plane of the wing determines the angle of attack the wing maintains in use. The pivot bars 41 extend freely through respective symmetrical slots or apertures 42 in the support core 39 each of which includes an arcuate portion 43 centred on a pivot portion 44 forming part of and terminating the opposite slot 43. As will be apparent the slot portions 44 extend inwardly towards each other.

In use, one pivot bar 41 may seat in the pivot portion 44 of one slot 42 whilst the opposite pivot bar 41 is free for but constrained for limited pivotal movement along the arcuate portion 43 of the opposite slot 42, the angular extent of which determine the limits desired in the adjustment angles of the wings 38. Dependant upon the apparent angle of the flow of water to the wings 38, the opposite bars 41 will seat in the opposite pivot portions 44 of the slots 42 and permit limited pivotal movement of the wings 38.

Operation of the wing assemblies 36 is more clearly illustrated in Figs. 12(a) to (d) with the arrows marked 45 indicating the apparent direction of water flow at any one time consequent on wave motion and the arrows 46 indicating the direction of lift generated by the wings 38. In Fig. 12(a), the angle of attack is relatively small and the lift direction through the centre of lift of the wing is offset from the pivot axis of the lower bar 41 defined by the lower pivot recess portion 44 thus creating a moment tending to increase the angle of attack however this is limited by the upper bar 41 abutting against the end of the upper slot portion 43. As the apparent flow direction changes as shown in Figs. 12 (b), the lift will first act through the pivot axis of the lower bar 41 so that no moment is created and then swing to a position past the pivot axis creating a moment causing pivotal movement of the upper bar 41 in the upper slot portion 43 and pivotal movement of the wings 38 to maintain optimum angle of attack of the wings 38 to apparent flow or angle of attack within a predetermined range.

Fig. 12(c) illustrates the position of the wings 38 and pivot mechanism at zero angle of attack with neither pivot bar 41 seated in its pivot recess 44 whilst Fig. 12(d) illustrates the wing position for opposite apparent flow to the wing. In use, the pivot points or axes of the wing assembly 36 will "switch" between the upper and lower pivot axes depending upon the apparent flow direction to maintain the wings 38 in their desired range of angle of attack.

In some circumstances, for example when applied to a hydrofoil-type arrangement intended to provide a constant lifting force irrespective of wave movement, the wings 38 may be supported for controlled pivotal movement about a single pivot axis either located above or below the wings 38.

The above described arrangements may also be applied to single wing sections as shown in Figs. 13 and 14. In Fig. 13, a single wing 45 is supported at each end by respective support cores 39' similar to the type 39 shown in Figs. 8 to 12. In this arrangement, each support core 39' is sandwiched between a pair of end plates or members 46 which are interconnected rigidly by respective pivot bars or shafts 47, which extend through the respective slots 42' to be maintained captive and be movable freely therein in the manner described above. The opposite ends of the wing sections 45 are secured to the inner end plates 46 so as to be guided for movement in a manner similar to that shown in Figs. 12(a) to (d). In this configuration, the cores 42' may be supported in a frame extending below the hull of the vessel or arranged on one or both sides of the



hull. Alternatively the opposite support cores 42' may be secured to the spaced hulls of a multihull vessel such as a catamaran or a trimaran.

In Figs. 14, a single wing 48 is supported in cantilever like fashion from a support cores 39' which may be secured to the hull of the vessel in any suitable manner for example in a bore in the hull and adhesively secured therein. Suitably, the wings 38, 45 or 48 may be made of fibreglass in a mould whilst the pivot bars or shafts 41 and 47 are preferably formed of a corrosion resistant material suitably stainless steel.

Referring now to Fig. 15 there is illustrated an alternative form of adjustable wing assembly 49 according to the present invention. In this embodiment, the adjustment is internal and for this purpose, the wing assembly 49 includes a symmetrical aerofoil sectioned wing portion 50 having a central longitudinally extending aperture 51 and a support 52 which extends through the aperture 51. The recess 40 includes opposite arcuate surfaces 53 which are centred on the desired pivotal axes of the wing portion 50 and the support 52 is provided with complimentary configured opposite surfaces 54. The aperture 51 also includes opposite leading surfaces 55 which converge from the curved surfaces 53 towards the leading edge of the wing portion 50 and the support 52 is provided with a corresponding wedge shaped converging leading portion 56. The support 52 and wing portion 50 cooperate in the manner shown in Fig. 16(a) to (d) and it will be seen that when the apparent flow is from below the wing portion 50 in the drawings, the wing portion 50 will be urged against the support 52 with the complimentary curved surfaces 53 and 54 cooperating and guiding the pivotal movement of the wing portion as the angle of attack varies. As the angle of attack decreases towards zero, the corresponding converging leading surfaces 55 and 56 of the support and wing will cooperate to maintain the wing portion 50 at a substantially zero angle of attack as it moves rearwardly relative to the support 52. As the flow direction changes towards the opposite side of the wing portion 50, the wing portion 50 will slide forwardly by virtue of the cooperation between the converging surfaces 55 and 56 until the opposite complimentary curved surfaces 54 and 53 engage to guide the wing portion 50 in a controlled pivotal movement, the extent of which is limited by the rear split portion 57 of the recess 40 which receives the "tail" of the support 52. Thus the wing portion 50 will maintain optimum angle of attack or have an angle of attack within a predetermined range irrespective of the direction of water flow in the same manner as the mechanism of Figs. 8 to 12, that is the wing is permitted to rotate about a pair of alternate pivot points positioned outside of, and on either side of the chordal plane and rearward of the center of lift of the aerofoil with a means of switching between pivots as the flow changes from above to below. Thus in the first described arrangement the pivot points are "real" whilst in the second (internal) arrangement the pivot points are "virtual", being the centers of curvature of the cooperating curved surfaces 53 and 54.

In a particularly preferred construction and as shown in Figs. 15 the wing portion 50 is formed of a plurality of juxtaposed individual segments 58 each of which has the cross section illustrated in Fig. 16. Each individual segment 58 may pivotally adjust independently on the support 52 to the flow conditions at its particular position so as for example to shape the aerofoil sectioned wing portion 50 to a twisted longitudinal form so that the optimum angle of attack is maintained at all positions along the length of the wing. Thus the appropriate angle of attack may be maintained both at the tip and root of the wing. Preferably the

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individual wing segments 58 as above are covered with a flexible skin material 59 to improve streamlined flow about the wing.

The principles of the present invention may also be applied to cause rotation of a rotor assembly for driving power generation means such as an electrical generator or any other load. The rotor assembly may include one or more rotors 60 as shown in Fig. 17 each of which includes a pair of aerofoil wing sections 61 arranged in end to end relationship in opposite configurations so that their leading edges point in the same direction of rotation. This rotor 60 is provided with a central shaft or rotational axis 62 arranged substantially normal to the chordal planes of the wing sections 61. The shaft 62 may be supported for rotational movement about a vertical axis with the rotor 60 submerged in water subject to wave action and in accordance with the above described principles, thrust will be extracted by the wing sections 61 from the waves to cause rotation of the rotor 60 in the direction indicated by the arrows. The shaft 62 may be coupled to a conventional electrical generator so that rotation thereof as a consequence of rotation of the wing sections 61 will drive the generator for the generation of electrical power. It will also be recognized that in accordance with the above principles, the shaft 62 may be arranged for rotation about any axis for example a horizontal axis, water flow impinging on the wing sections 62 causing rotation of the rotor 60 in one direction only.

Figs. 18 and 19 illustrate an alternative form of rotor assembly 63 which in this instance includes a central hub 64 and a plurality of wing sections 65 (in this instance four) extending outwardly from the hub 64. In this rotor the wing sections 65 taper in cross section towards their tips to reduce tip losses. This rotor assembly 63 when submerged in water subject to wave action will function in the same manner as the Fig. 17 embodiment to convert kinetic energy of the waves into a thrust to cause rotation of the rotor assembly 63.

A plurality of rotor assemblies 63 of the type illustrated in Figs. 18 and 19 may be ganged together on a single shaft as illustrated in Fig. 20. Furthermore, the shaft 66 to which the rotors 63 may be secured may either comprise a rigid shaft or alternatively a flexible member such as a cable and suitably the shaft or cable carrying the rotor assemblies is longer than the expected wave length.

In an alternative construction shown in Fig. 21, a rotor assembly 67 for the above purpose may be constructed to include a plurality of aerofoil sectioned blades 68 which are supported at a position radially spaced from the axis of rotation of the rotor assembly 67 to extend generally longitudinally relative to that axis. Preferably, the blades 68 are supported on respective radially extending arms 69 which are interconnected at their inner ends suitably via a hub 70. Preferably the blades 68 are symmetrical about the circular circumference line along which they travel and extend along the surface of revolution of the rotor assembly. Alternatively, the blades in cross section may be tangential to the surface of revolution. The wing sectioned blades 68 in this embodiment are arranged to sweep out a cylindrical path on rotation of the rotor assembly 67. In an alternative embodiment, the wing sectioned blades 68 may lie along the surface of a cone so as to sweep a conical surface on rotation and in this instance the blades are suitably symmetrical about that conical surface. As shown in Fig. 22, this rotor assembly 67 is supported for rotation about an axis extending generally parallel to the wave fronts so that maximum energy is transferred from the agitated water particles to the wing sectioned blades 68 to cause rotation of the rotor assembly 67.

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Fig. 23 illustrates a typical application of the rotors of the present invention. In this arrangement a shore based generating plant 72 is driven by a rotor assembly 73 comprising a shaft 74 having a plurality of rotors 75 mounted thereon as shown in Fig. 24. The shaft 74 being connected to the shore based generating plant acts as a restraint against movement of the aerofoil sectioned blades of the rotors in a direction perpendicular to their chordal planes and the kinetic energy of wave agitated water particles will be converted into a unidirectional thrust by the aerofoil sectioned blades to rotate the rotor assembly 73 and drive the generating plant.

In the embodiments of Figs. 25 and 26, the principles of the present invention are applied to power navigation lights. In Fig. 25, the navigation light 76 is supported on a floating buoy 77 or other floating body which also defines a support for an electrical generator 78 which is adapted to power the light 76. The generator shaft is coupled only to the upper rotor 80 which is supported rotatably on a shaft 81 whilst a further rotor 82 of opposite configuration and which therefore rotates in an opposite direction is supported on the shaft 81 at a spaced position from the rotor 80 so that the perpendicular components of the lift forces generated by the respective rotors cancel each other out. It will also be seen that the shaft 80 may be anchored by means of an anchor line 83 so that the light may be located in a desired area of operation. Alternatively, the blade 80 may be fixed to the generator body and the generator shaft secured to the rotor 82, the generator body and shaft being caused to rotate in opposite directions by the respective rotors.

In Fig. 26, the constraint against vertical movement of the rotor due to the perpendicular components of the lift forces is provided by the sea bed. In this embodiment, a navigation light 84 is again powered by a generator 85 driven by a rotor 86 for example of the type illustrated in Fig. 18. The rotor 86 is fixed against vertical movement by means of a support 87 fixed to the sea bed 88. In both the embodiments of Figs. 25 and 26, the generator for the navigation lights are driven by rotors which will extract kinetic energy from the waves and convert that energy into thrust.

In Fig. 27, the constraint against substantial vertical movement of the rotor is provided by the hull 89 of a yacht. In this arrangement, a generator, bilge pump, or other load 90 is supported in a fixed position on a frame 91 which extends from the stern of the vessel. The load 90 is coupled to a rotor 92 which will rotate when subject to wave action to thereby drive the load.

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## CLAIMS

1. A method of extracting energy from waves by using an aerofoil sectioned wing and cause said wing to move in a desired direction along a path comprising the steps of

- a) at least partially submerging said wing in water agitated by wave action with its leading edge forward in said desired direction of travel and its transverse chordal plane fixed substantially parallel to said direction
- b) supporting said wing for movement along said path, and
- c) constraining said wing against substantial movement perpendicular to said path.

2. A method of applying thrust to a submerged or partly submerged body to cause movement thereof in a desired direction along a path, said method including the steps of fixedly securing an aerofoil sectioned wing to said body so that said wing is at least partially submerged and subject to water agitated by wave action, said wing having its leading edge forward in the desired direction of travel and its transverse chordal plane substantially parallel to said direction, said body constraining said wing against substantial movement perpendicular to said path.

3. A vessel or other body having a submergible or partly submergible hull, at least one aerofoil sectioned wing secured to said hull and extending laterally thereof so that said wing has its leading edge forward relative to the normal direction of movement of said vessel and its transverse chordal plane substantially parallel to said direction, said vessel constraining said wing against substantial movement perpendicular to said direction.

4. A vessel according to claim 3 wherein said wing has an aspect ratio of at least five to one.

5. A vessel according to claim 3 and including a plurality of said wings secured to said hull at spaced intervals therealong so that lift force components generated in opposite directions perpendicular to said chordal plane substantially cancel each other out.

6. A vessel according to claim 5 wherein said wings are spaced apart over a distance greater than the wave length of waves in which said vessel is operating.

7. A vessel according to claim 3 wherein said wing is pivotally secured to said hull for movement between a first operative attitude extending laterally of said hull and a second inoperative position extending generally along said hull.

8. A vessel according to claim 7 and including a housing secured to said hull, said wing when in its said inoperative position being disposed substantially within said housing.

9. A vessel according to claim 7 and including biasing means associated with said wing and adapted to maintain said wing in said operative attitude but permitting pivotal movement of said wing against the bias

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of said biasing means in the event of said wing striking an obstruction or being overstressed.

10. A vessel according to claim 7 wherein said wing is supported on said hull for pivotal movement in opposite directions perpendicular to said chordal plane and there being provided biasing means opposing pivotal movement of said wing away from its operative laterally extending attitude but permitting pivotal movement of said wing in the event of overstressing.

11 A vessel or other body having a submerged or partly submerged hull, a plurality of aerofoil sectioned wings secured to said hull at spaced positions therealong and extending laterally therefrom so as to be exposed in use to water agitated by wave action, said wings having their leading edges forward relative to the normal direction of movement of said vessel and their chordal planes disposed substantially parallel to said direction, said hull defining a substantially rigid link between said wings so that lift force components generated by the respective said wings in opposite directions perpendicular to said chordal planes substantially cancel each other out.

12. A vessel or other body having a submerged or partly submerged hull, and a wing assembly secured to said hull so as to be exposed to water agitated by wave action, said wing assembly including at least one symmetrical aerofoil sectioned wing having its leading edge forward in the normal direction of movement of said vessel and support means for said wing, said support means supporting said wing for pivotal movement about an axis disposed rearwardly of the centre of lift of said wing and to one side of the chordal plane of said wing whereby lift forces generated in said wing act about said pivot axis to vary the attitude of said wing and maintain said wing within a predetermined range of angles of attack in accordance with the direction of apparent flow.

13. A vessel according to claim 12 wherein said support means defines respective pivot axes for said wing disposed symmetrically on opposite sides of said chordal plane and wherein said support means permits switching of the operative pivot axis of said wing between said respective pivot axes in accordance with the direction of apparent flow.

14. A wing assembly including a symmetrical aerofoil sectioned wing and support means for said wing, said wing being supported on said support means for pivotal movement about an axis disposed rearwardly of the centre of lift of said wing and to one side of the chordal plane of said wing whereby lift forces generated in said wing when said wing is disposed in a fluid medium act about said pivot axis to vary the attitude of said wing to maintain said wing within a predetermined range of angles of attack relative to apparent flow of said medium.

15. A wing assembly according to claim 14 wherein said support means defines respective pivot axes for

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said wing disposed symmetrically on opposite sides of said chordal plane and wherein said support means permits switching of the operative pivot axis of said wing between said respective pivot axes in accordance with the direction of apparent flow of said medium.

16. A wing assembly according to claim 15 wherein said support means includes a pair of support shafts disposed along the respective pivot axes and fixed rigidly to said wing and a support structure defining respective pivot recesses for said shafts, said support structure including means to maintain the operative said shaft in its pivot recess during pivotal movement of said wing about its respective axes.

17. A wing assembly according to claim 15 wherein said wing includes a central aperture having opposite curved surfaces centred on the respective said pivot axes and wherein said support means is disposed within said recesses and includes surfaces complementary to said curved surfaces for sliding engagement therewith to guide said wing in its pivotal movement.

18. A rotor assembly including at least one blade having in cross section the form of an aerofoil sectioned wing, said blade being supported to one side of the axis of rotation of said rotor and having its leading edge forward in direction of rotation of said rotor, said blade further having its chordal plane disposed in or tangential to the surface of rotation of said rotor, said rotor being submerged in water agitated by wave action and being supported so that said blade is constrained against substantial movement perpendicular to said chordal plane.

19. A rotor assembly according to claim 18 wherein said blade lies along the curved surface of a cylinder, cone or sphere.

## AMENDED CLAIMS

[received by the International Bureau on 07 July 1987 (07.07.87);  
original claims 1-19 replaced by amended claims 1-25 (4 pages)]

1. A method of extracting energy from waves by using an aerofoil sectioned wing and so as to cause said wing to move in a desired direction along a generally linear path extending transversely of said wing comprising the steps of
  - a) providing an aerofoil sectioned wing having a non-adjustable profile and a substantially fixed chordal plane.
  - b) at least partially submerging said wing so as to be exposed directly to water agitated by wave action, said wing having its leading edge forward in said desired direction of travel and its chordal plane disposed substantially parallel to said direction
  - c) supporting said wing for movement along said path, and
  - d) constraining said wing against substantial displacement perpendicular to said path.
2. A method according to claim 1 wherein said wing has an aspect ratio of at least five to one.
3. A method of applying thrust to a submerged or partly submerged elongate body to cause movement thereof in a desired direction along a path extending longitudinally of said body, said method including the steps of :-
  - a) providing an aerofoil sectioned wing;
  - b) supporting said wing to said body so that said wing is fixed relative to said body for movement therewith, said wing having its leading edge forward in the desired direction of movement of said body and its chordal plane fixed substantially parallel to said direction;
  - c) at least partially submerging said wing so as to be directly subject to water agitated by wave action; said body substantially constraining said wing against displacement perpendicular to said path.
4. A method according to claim 3 wherein said wing has an aspect ratio of at least five to one.
5. A vessel or other body having a submersible or partly submersible hull, at least one aerofoil sectioned wing secured to said hull to be fixed relative to said hull for movement therewith, said wing extending laterally of said hull and having its leading edge forward relative to the normal direction of movement of said vessel and its chordal plane fixed, substantially parallel to said direction, said wing in use being directly exposed to water agitated by wave action and said vessel being such as to substantially constraining said wing against displacement perpendicular to said direction.
6. A vessel or other body according to claims 5 wherein said wing has an aspect ratio of at least five to one.

7. A vessel according to claim 5 and including a plurality of said wings secured to said hull at spaced intervals therealong so that lift force components generated in opposite directions perpendicular to said chordal plane substantially cancel each other out.

8. A vessel according to claim 7 wherein said wings are spaced apart over a distance greater than the wave length of waves in which said vessel is operating.

9. A vessel according to claim 5 wherein said wing is pivotally secured to said hull for movement between a first operative attitude extending laterally of said hull and a second inoperative position extending generally along said hull.

10. A vessel according to claim 9 said hull including housing means, said wing when in its said inoperative position being disposed substantially within said housing means.

11. A vessel according to claim 9 and including biasing means associated with said wing and adapted to maintain said wing in said operative attitude but permitting pivotal movement of said wing against the bias of said biasing means in the event of said wing striking an obstruction or being overstressed.

12. A vessel according to claim 5 wherein said wing is supported to said hull for pivotal movement in opposite directions about an axis extending longitudinally of said hull and there being provided biasing means opposing pivotal movement of said wing away from its operative laterally extending attitude but permitting pivotal movement of said wing in the event of oversteering.

13. A vessel or other body having a submerged or partly submerged hull, a plurality of aerofoil sectioned wings secured to said hull so as to be fixed relative to said hull for movement therewith, said wings being disposed at spaced positions therealong and extending laterally therefrom so as to be directly exposed in use to water agitated by wave action, said wings having their leading edges forward relative to the normal direction of movement of said vessel and their chordal planes fixed substantially parallel to said direction, said hull defining a substantially rigid link between said wings so that lift force components generated by the respective said wings in opposite directions perpendicular to said chordal planes substantially cancel each other out.

14. A vessel or other body having a submerged or partly submerged hull, and a wing assembly supported to said hull so as to be exposed to water agitated by wave action, said wing assembly including at least one symmetrical aerofoil sectioned wing having its leading edge forward in the normal direction of movement of said vessel and support means for supporting said wing to said hull, said support means supporting said wing for pivotal movement about an axis disposed



rearwardly of the centre of lift of said wing and to one side of the chordal plane of said wing whereby lift forces generated in said wing act about said pivot axis to vary the attitude of said wing and maintain said wing within a predetermined range of angles of attack in accordance with the direction of apparent flow.

15. A vessel according to claim 14 wherein said support means defines respective pivot axes for said wing disposed on opposite sides of said chordal plane and wherein said support means permits switching of the operative pivot axis of said wing between said respective pivot axes in accordance with the direction of apparent flow.

16. A wing assembly including a symmetrical aerofoil sectioned wing and support means for said wing, said wing being supported on said support means for pivotal movement about an axis disposed rearwardly of the centre of lift of said wing and to one side of the chordal plane of said wing whereby aerodynamic or hydrodynamic lift forces generated in said wing when said wing is disposed in a flow in a fluid medium act about said pivot axis to vary the attitude of said wing to maintain said wing within a predetermined range of angles of attack relative to apparent flow of said medium.

17. A wing assembly according to claim 16 wherein said support means defines respective pivot axes for said wing disposed symmetrically on opposite sides of said chordal plane and wherein said support means permits switching of the operative pivot axis of said wing between said respective pivot axes in accordance with the direction of apparent flow of said medium.

18. A wing assembly according to claim 17 wherein said support means includes a pair of support shafts disposed along the respective pivot axes and fixed rigidly to said wing and a support structure defining respective pivot recesses for said shafts, said support structure including means to maintain the operative said shaft in its pivot recess during pivotal movement of said wing about its respective axes.

19. A wing assembly according to claim 17 wherein said wing includes a central aperture having opposite curved surfaces centred on the respective said pivot axes and wherein said support means is disposed within said recess and includes surfaces complementary to said curved surfaces for sliding engagement therewith to guide said wing in its pivotal movement.

20. A wing assembly according to Claim 19 wherein said wing includes a plurality of independent juxtaposed segments of symmetrical aerofoil form, each said segment having said opposite curved surfaces cooperable with said complementary surfaces of said support means whereby to be independently adjustable relative thereto.

21. A wing assembly according to Claim 20 and including a flexible skin covering said segments.

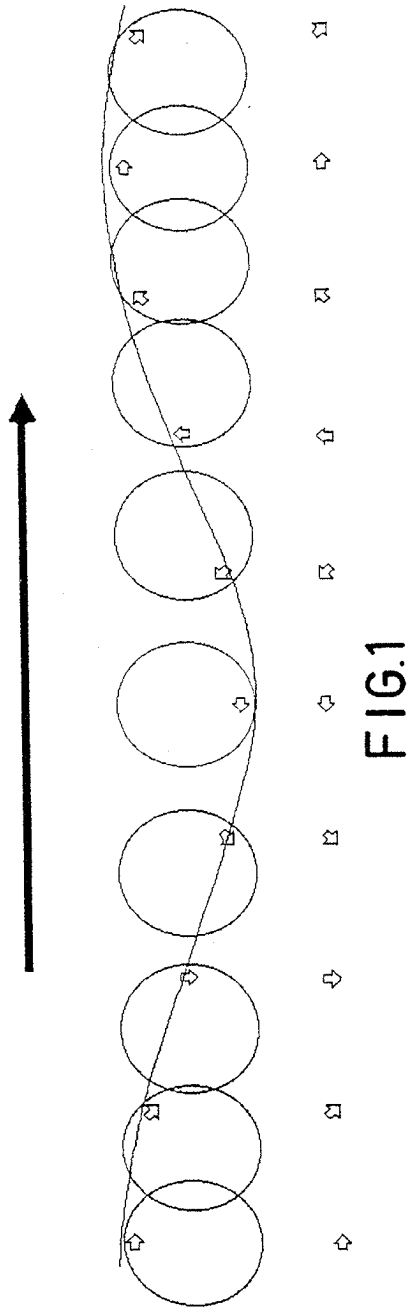
22. A rotor assembly including at least one blade having in cross section the form of an aerofoil sectioned wing said blade being supported to one side of the axis of rotation of said rotor and having its leading edge forward in the direction of rotation of said rotor and wherein said blade extends along the curved surface of a surface of revolution centered on said axis of rotation and has its chordal plane disposed in or tangential to said surface, said rotor being submerged or partially submerged in water agitated by wave action and being supported so that said blade is constrained against substantial movement perpendicular to said chordal plane.

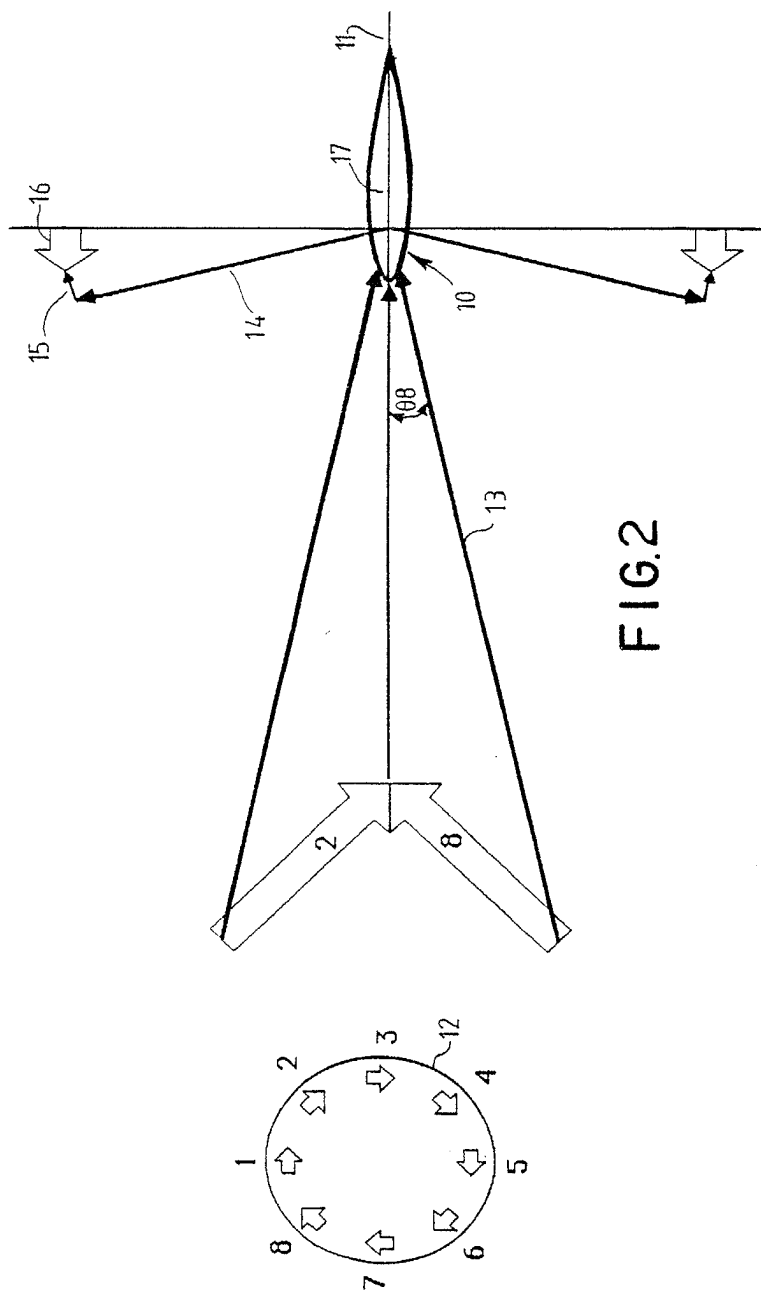
23. A rotor assembly according to Claim 22 wherein said surface of revolution comprises the surface of a cylinder, cone or sphere.

24. A rotor assembly including a plurality of rotors and elongated support means for said rotors extending along the axis of rotation of said rotor assembly, said rotors being fixed to said elongated support means for rotational movement therewith, and each said rotor including at least one blade having in cross section the form of an aerofoil sectioned wing, said blade being supported to one side of the axis of rotation of said rotor and having its leading edge forward relative to the direction of rotation of said rotor, said blade further having its chordal plane disposed in or tangential to the surface of rotation of said rotor, said rotor being submerged in water agitated by wave action and wherein said rotors are spaced apart along said support means a distance at least as long as the wave length of the waves in which said rotor assembly is operating so that said blades of said rotors are constrained against substantial movement perpendicular to their chordal planes by the statistical averaging effect of the individual, interconnected, rotors being acted upon, at any one time, by different parts of the wave cycle.

25. A rotor assembly according to Claim 24 wherein said elongated support means comprises a rigid shaft or flexible cable means.

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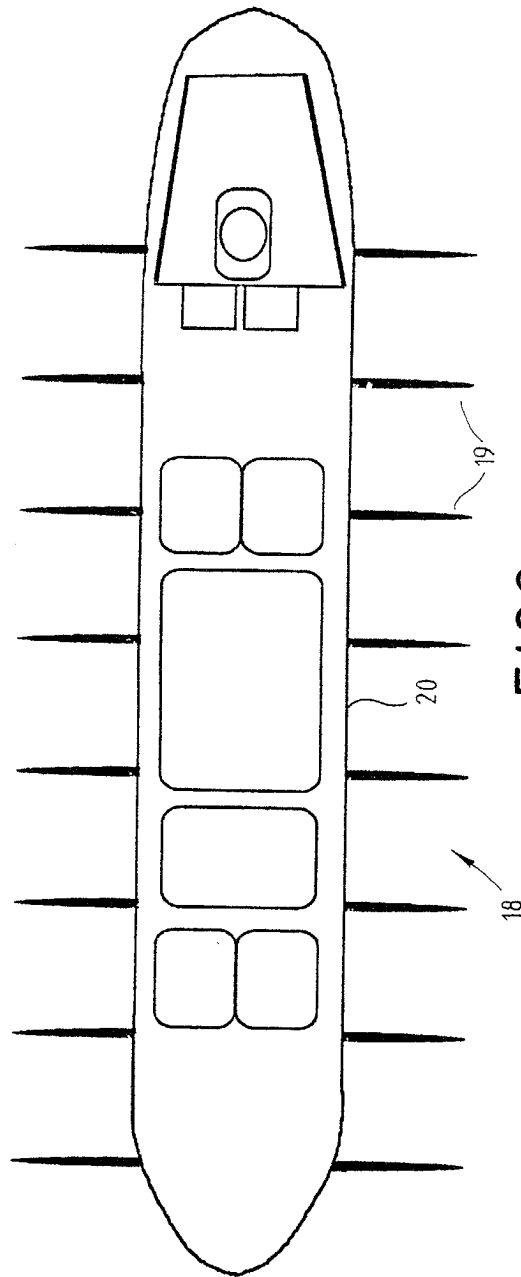


FIG. 3

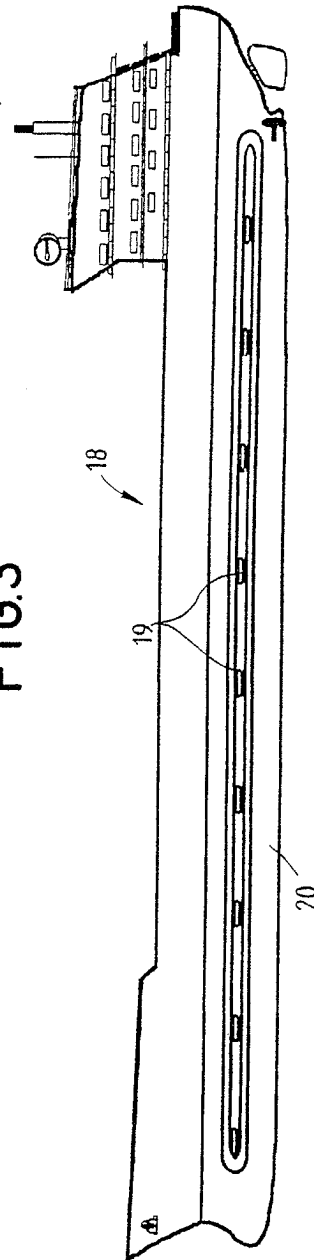
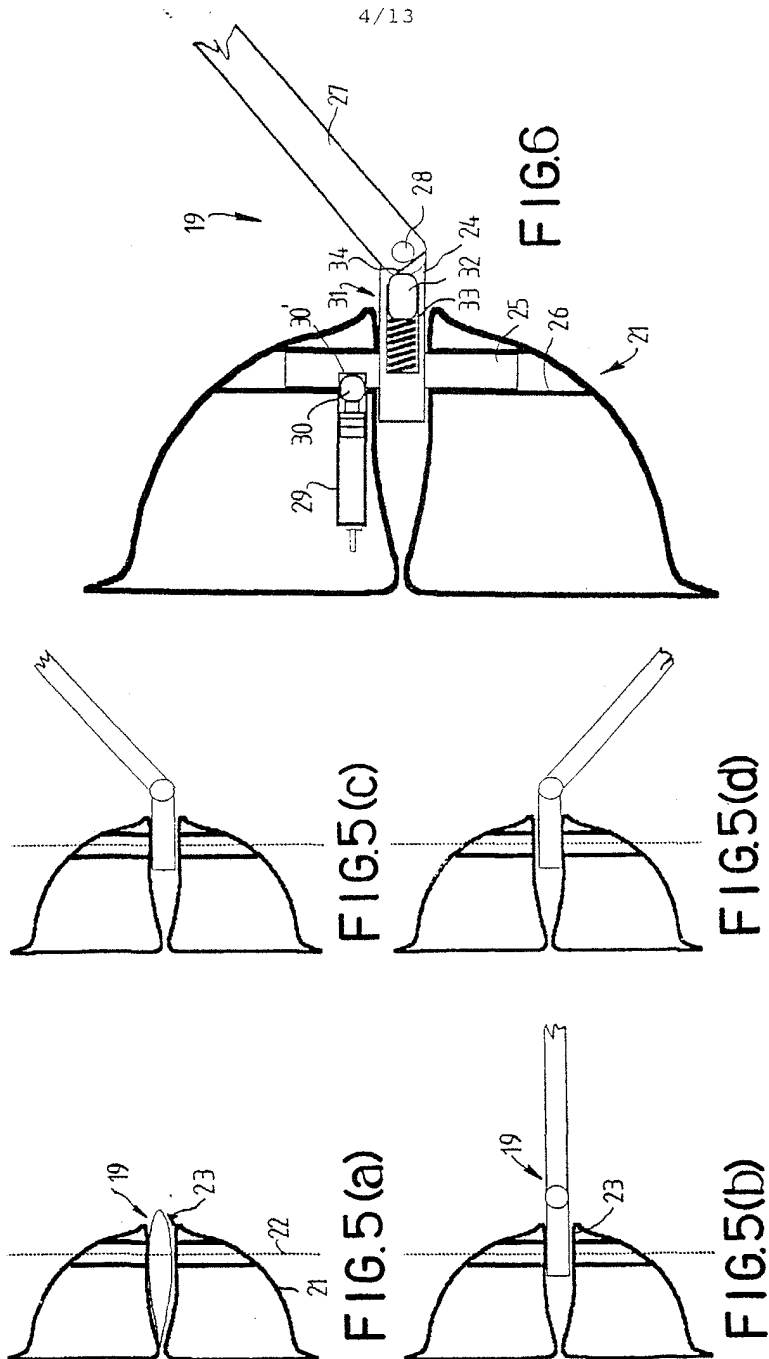
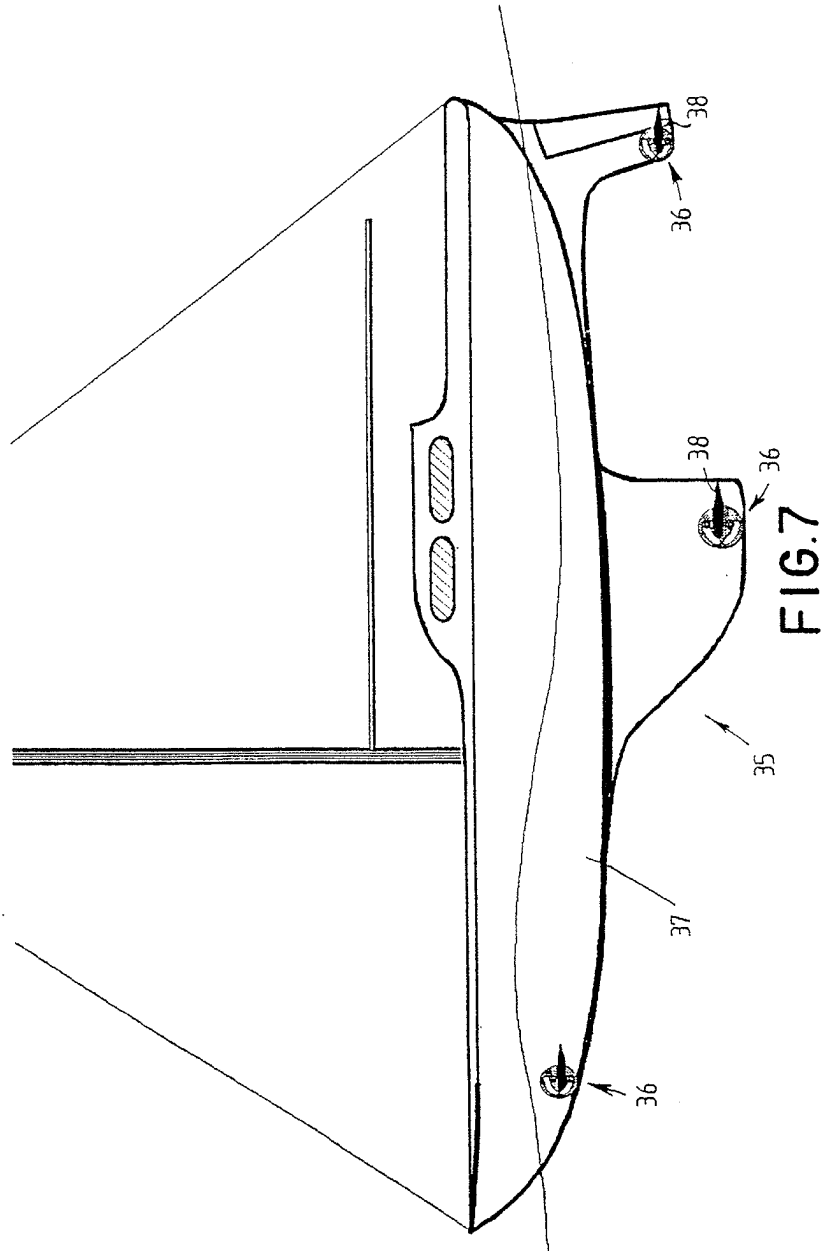


FIG. 4





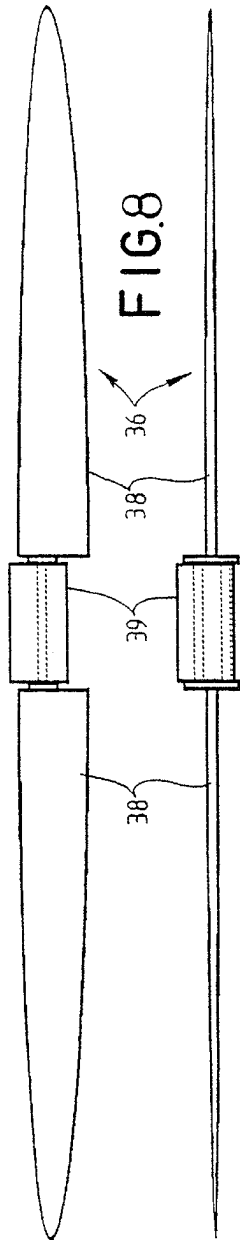


FIG. 9

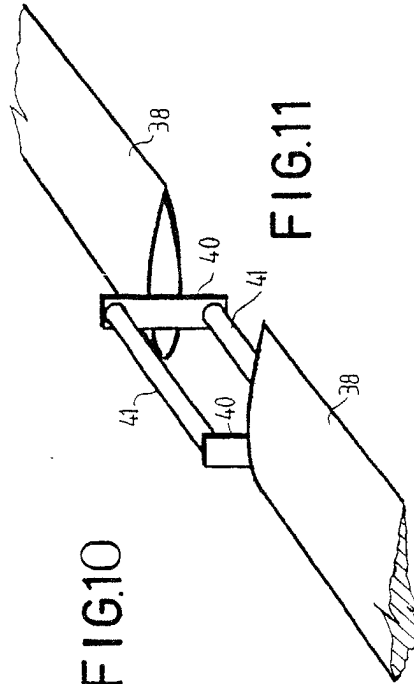


FIG. 10

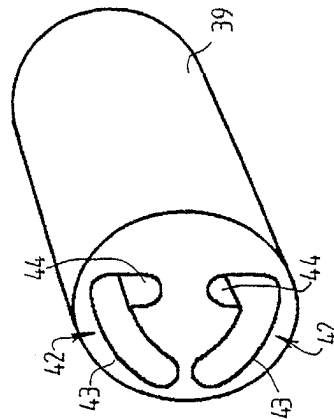
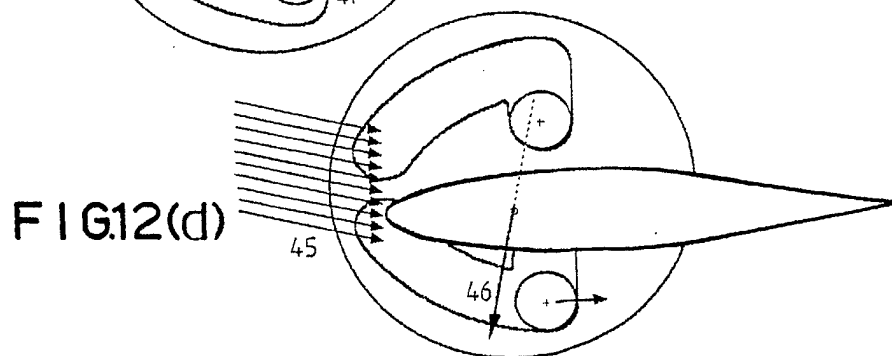
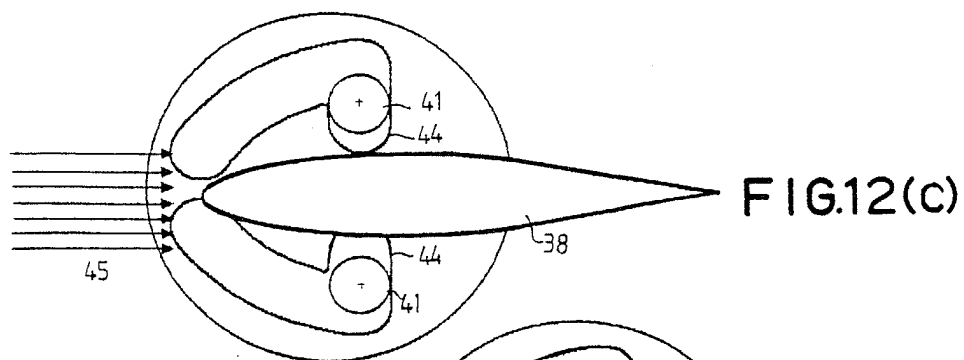
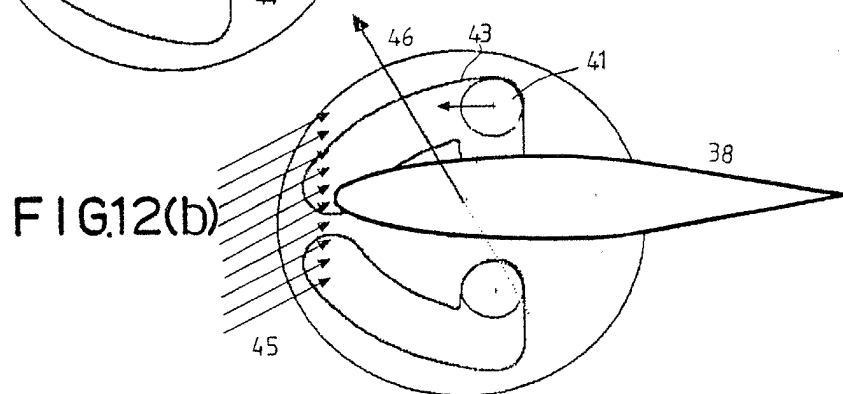
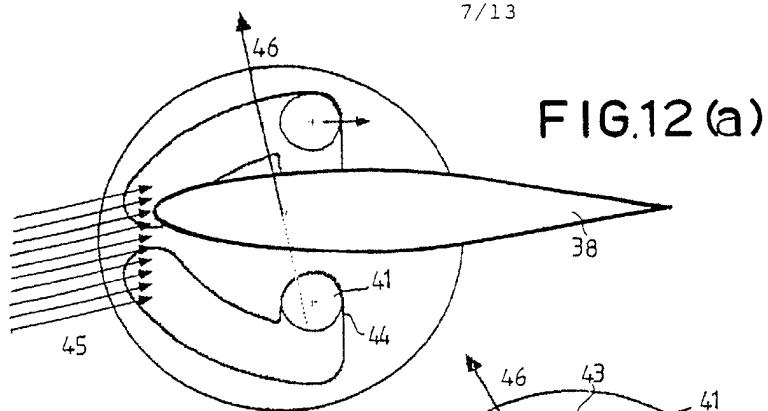
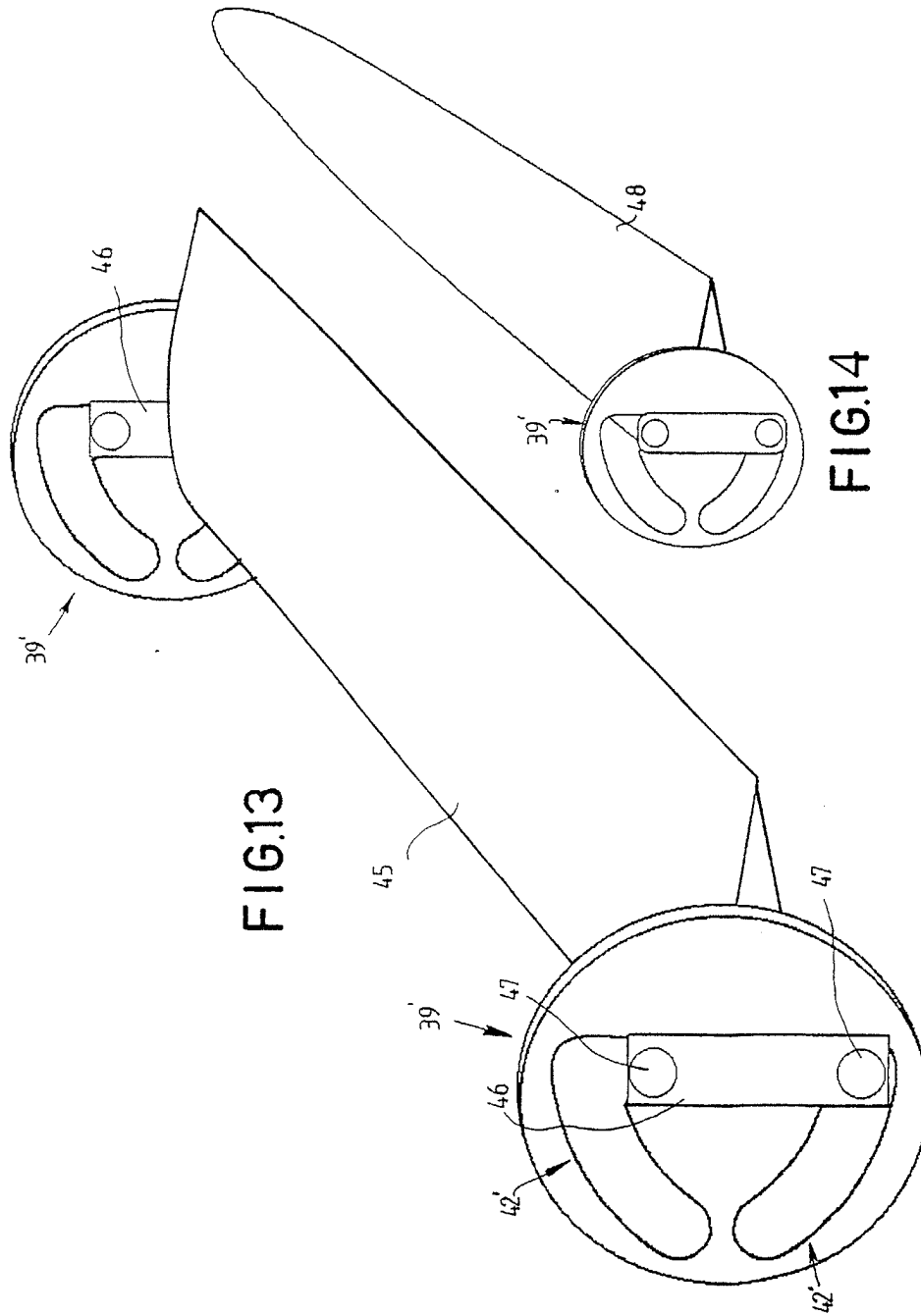


FIG. 11







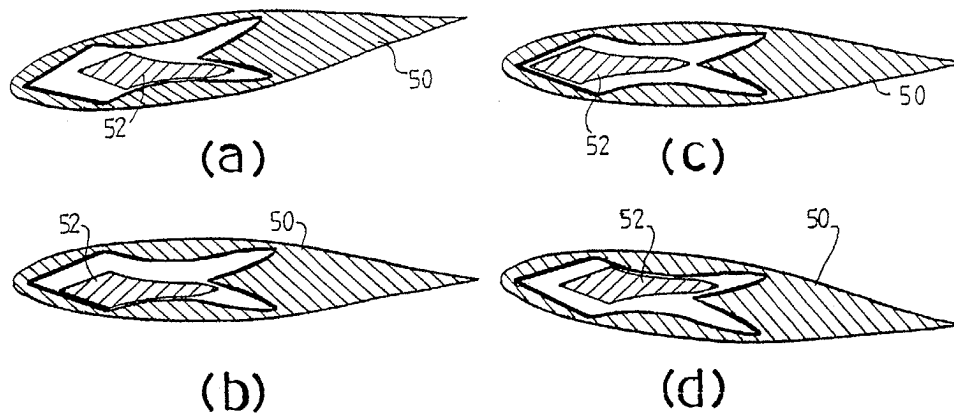
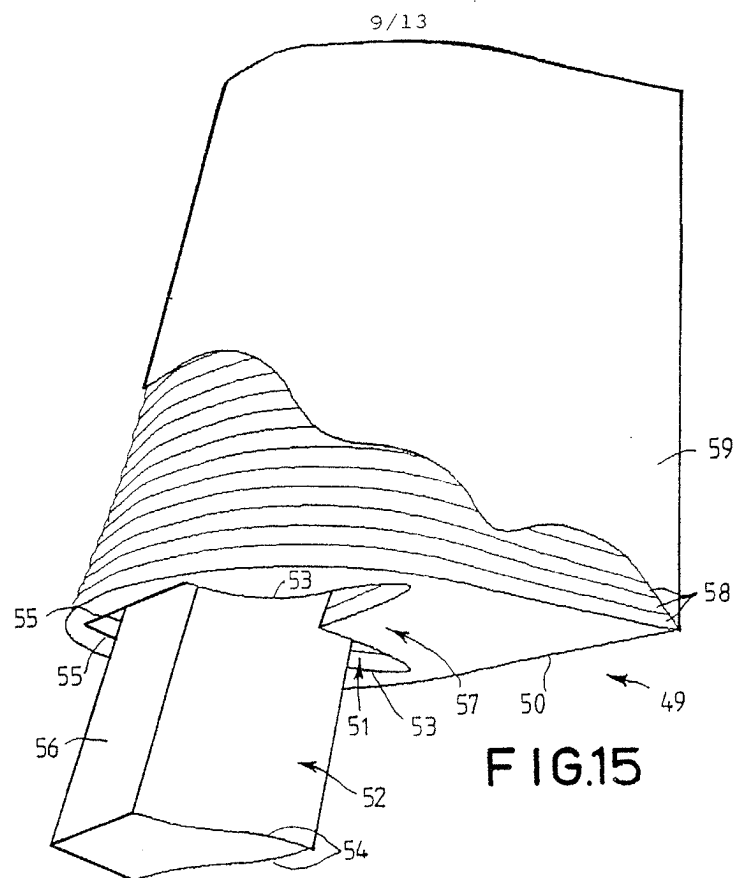


FIG. 16

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FIG.17

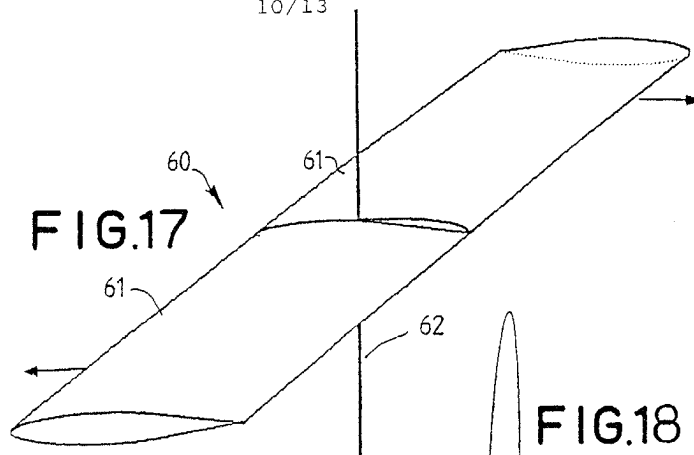


FIG.18

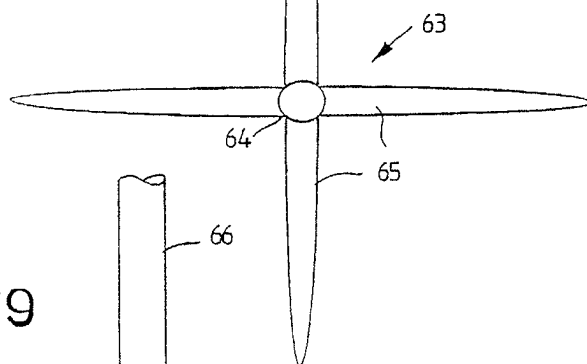


FIG.19

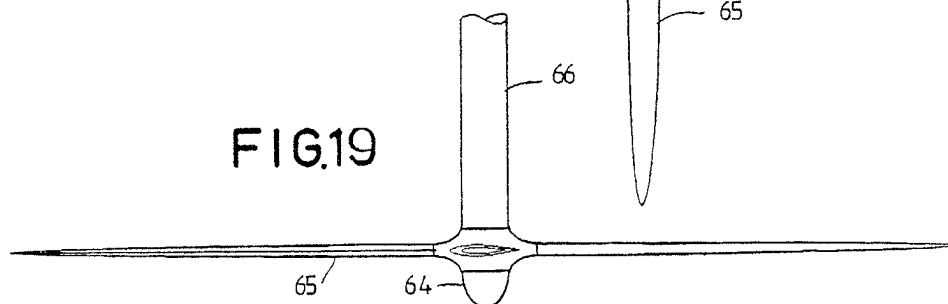


FIG.20

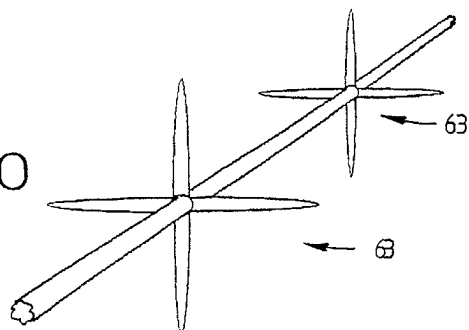


FIG.21

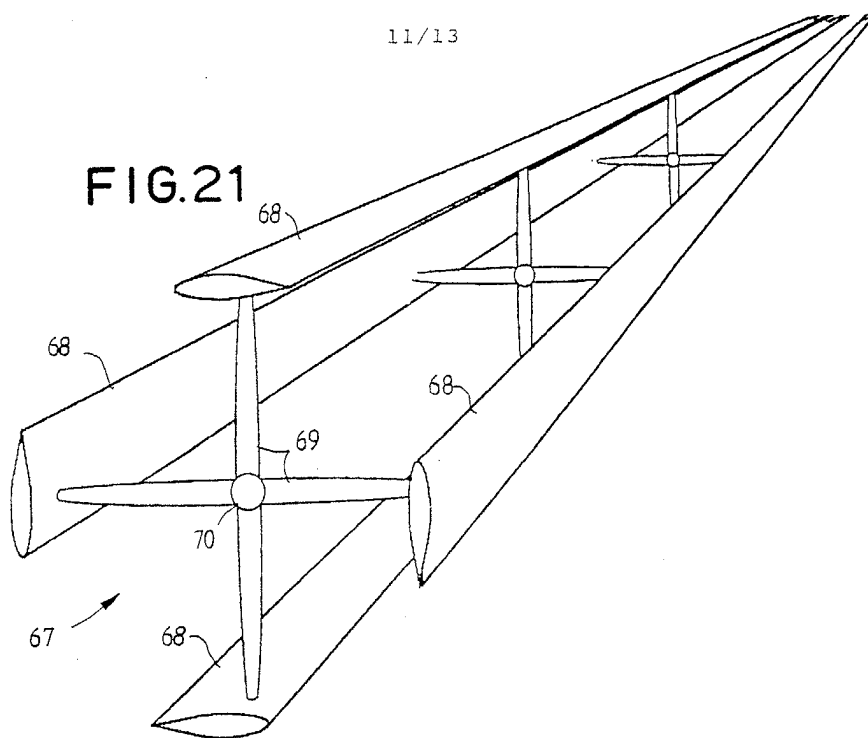
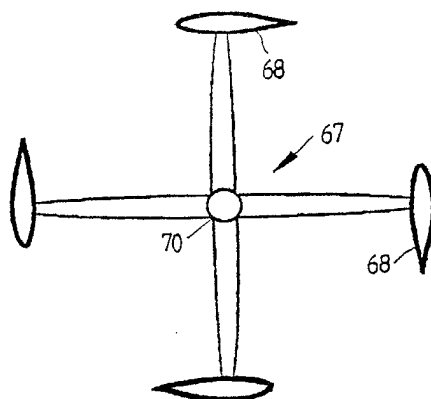


FIG.22



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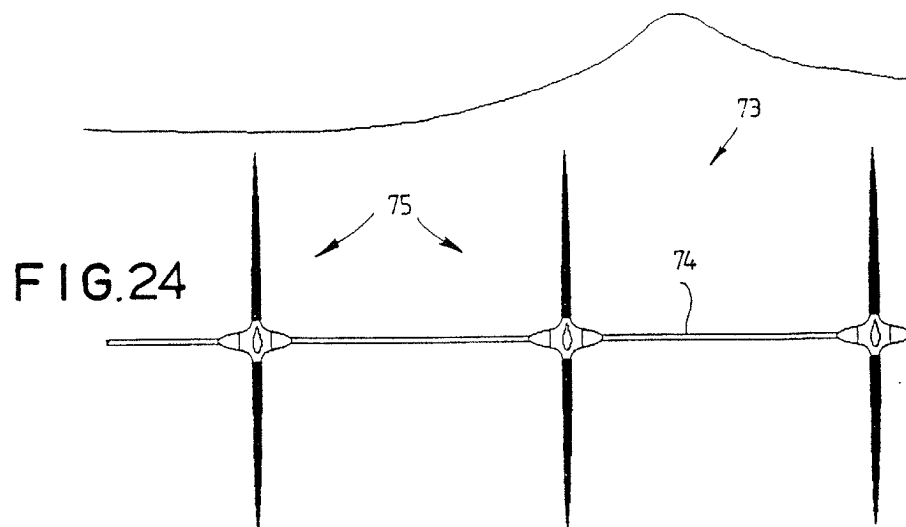
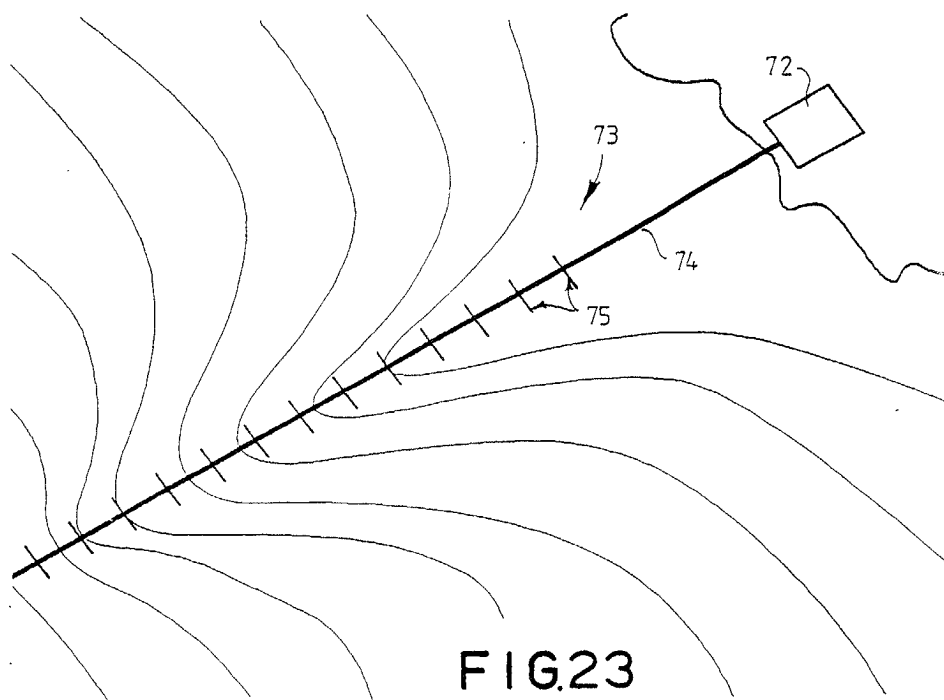


FIG.27

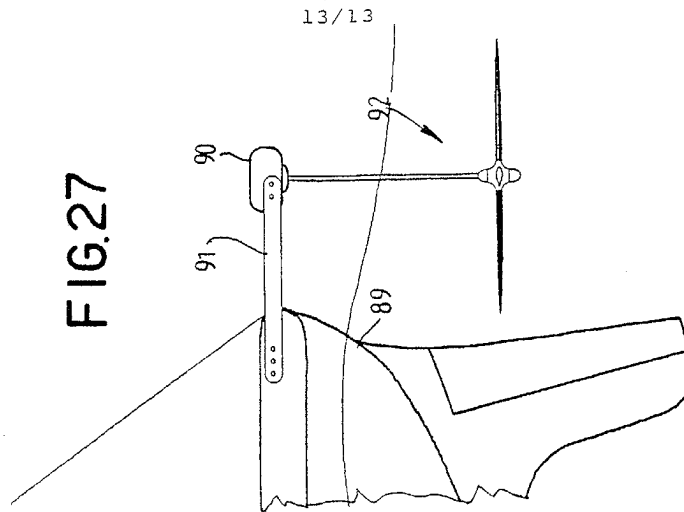


FIG.26

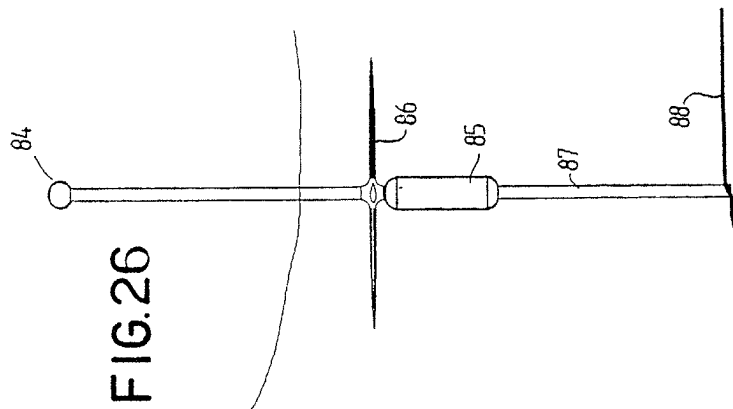
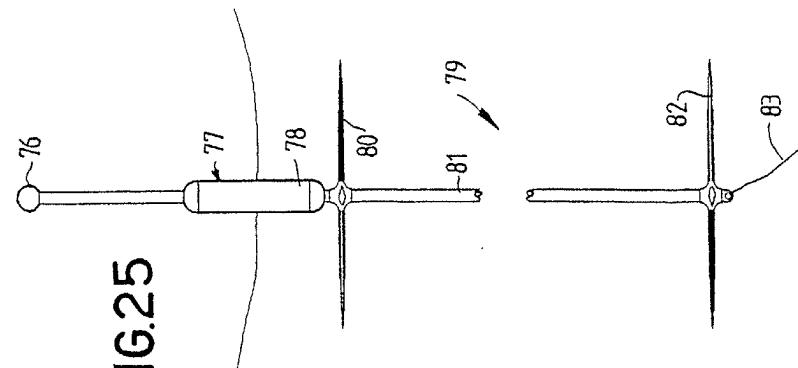


FIG.25



# INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 87/00016

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int. Cl. <sup>4</sup> B63H 19/02, E02B 9/08, F03B 13/14		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
IPC	B63H 19/02, E02B 9/08, F03B 13/12, 13/14, B63B 1/28, 39/06, B64C 3/38	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched *		
AU : IPC as above; Australian Classification 90.3.5		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> *		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	WO,A1, 80/01674 (HARTMANN) 21 August 1980 (21.08.80)	(1-3,18)
X	DE,A1, 2740939 (WERNER) 22 March 1979 (22.03.79)	(1-3)
X	CA,A, 1083926 (THE ENGLISH ELECTRIC COMPANY LIMITED) 19 August 1980 (19.08.80)	(1,2,18)
X	US,A, 3453981 (GAUSSE) 8 July 1969 (08.07.69)	(1-3)
X	US,A, 3312186 (LITSHEIM) 4 April 1967 (04.04.67)	(1-3)
X	JP,A2, 59-140196 (HITACHI ZOSEN K.K.) 11 August 1984 (11.08.84) (JAPATIC English Language Abstract)	(1-3)
X	JP,A2, 59-140197 (HITACHI ZOSEN K.K.) 11 August 1984 (11.08.84) (JAPATIC English Language Abstract)	(1-3)
X	JP,A2, 60-104491 (MITSUBISHI JUKOGYO K.K.) 8 June 1985 (08.06.85) (JAPATIC English Language Abstract)	(1-3)
X	SU,A, 1131-770 (SENKIN) 30 December 1984 (30.12.84) (Derwent English Language Abstract Q24 WEEK 8528)	(1-3)
X	The Motor Ship, Volume 64, Number 757, Issued August 1973 'Wave Power for Ship Propulsion', pages 67,68	(1-3)
(Continued)		
<p>* Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
4 May 1987 (04.05.87)	(07.05.87) 7 MAY 1987	
International Searching Authority	Signature of Authorized Officer	
Australian Patent Office	(O.L. HAGGAR)	

Form PCT/ISA/210 (second sheet) (January 1985)



## FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	AU, 8, 23261/77 (514742) (HADDOCK) 21 September 1978 (21.09.78)	(12-17)
A	US, A, 4220109 (CHOLET) 2 September 1980 (02.09.80)	(12-17)
A	US, A, 3015298 (BELL et al) 2 January 1962 (02.01.62)	(12-17)

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE <sup>1</sup>

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ..... because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers ..... because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers ..... because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING <sup>2</sup>

This International Searching Authority found multiple inventions in this international application as follows:

Claims 1-11, 18, 19 are directed to methods or devices including an aerofoil shaped wing under the influence of water movement in wave action.

Claims 12-17 are directed to substance to support means for a wing.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

## Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON  
INTERNATIONAL APPLICATION NO. PCT/AU 87/00016

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Members	
WO 80/01674	EP 23501		
DE 2740939			
CA 1083926			
US 3453981			
AU 23261/77	CA 1062091 US 4280433	FR 2344441	GB 1567395
US 4220109	AU 40094/78 DE 2841093 FR 2404254 JP 54057780 SE 7809936	BE 870541 DK 4198/78 GB 2005209 NL 7809618 SU 938755	CA 1108482 ES 473558 IT 1099138 NO 783229

END OF ANNEX